PATENT COOPERATION TI ATY

From the INTERNATIONAL BUREAU

To:

BOWDERY, Anthony, Oliver
Defence Evaluation & Research
Agency
D/IPD (DERA) Formalities
A4 Building, Ively Road
Farnborough
Hampshire GU14 0LX
ROYAUME-UNI

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

Date of mailing (day/month/year) 11 May 2000 (11.05.00)	
Applicant's or agent's file reference IPD/P3139/WOD	**IMPORTANT NOTIFICATION**
International application No. PCT/GB99/03055	**International filing date** (day/month/year) 14 September 1999 (14.09.99)

1. The following indications appeared on record concerning:

☐ the applicant ☐ the inventor ☒ the agent ☐ the common representative

Name and Address	State of Nationality	State of Residence
TURNER, James, Arthur D Young & Co. 21 New Fetter Lane London EC4A 1DA United Kingdom		
	Telephone No. +44 2380 634816	
	Facsimile No. +44 2380 224262	
	Teleprinter No.	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

☒ the person ☐ the name ☐ the address ☐ the nationality ☐ the residence

Name and Address	State of Nationality	State of Residence
BOWDERY, Anthony, Oliver Defence Evaluation & Research Agency D/IPD (DERA) Formalities A4 Building, Ively Road Farnborough Hampshire GU14 0LX United Kingdom		
	Telephone No. 01252 392710	
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	Teleprinter No.	

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

☒ the receiving Office
☐ the International Searching Authority
☒ the International Preliminary Examining Authority
☐ the designated Offices concerned
☒ the elected Offices concerned
☐ other:

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Anman QIU Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Assistant Commissioner for Patents
United States Patent and Trademark Office
Box PCT
Washington, D.C.20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 11 May 2000 (11.05.00)	
International application No. PCT/GB99/03055	**Applicant's or agent's file reference** IPD/P3139/WOD
International filing date (day/month/year) 14 September 1999 (14.09.99)	**Priority date** (day/month/year) 14 September 1998 (14.09.98)
Applicant SMITH, Peter, George, Robin et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

07 April 2000 (07.04.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Anman QIU Telephone No.: (41-22) 338.83.38

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PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference IPD/P3139/WOD	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/GB99/03055	International filing date *(day/month/year)* 14/09/1999	Priority date *(day/month/year)* 14/09/1998
International Patent Classification (IPC) or national classification and IPC G02B6/12		
Applicant THE SECRETARY OF STATE FOR DEFENCE et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 4 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 6 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☐ Certain defects in the international application
   VIII ☒ Certain observations on the international application

Date of submission of the demand 07/04/2000	Date of completion of this report 21.11.2000
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Lord, R Telephone No. +49 89 2399 2580

Form PCT/IPEA/409 (cover sheet) (January 1994)

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:
Description, pages:

2,4-11	as originally filed			
1,1a,3,3a	as received on	13/09/2000	with letter of	11/09/2000

Claims, No.:

1-12	as received on	13/09/2000	with letter of	11/09/2000

Drawings, sheets:

1/4-4/4	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-12
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-12
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-12
	No:	Claims	

2. Citations and explanations
   see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Conc rning S ction V

Claims 1 and 11

Subject to the comments in Section VIII of this Report, claims 1 and 11 appear to define an arrangement which would not be derivable from the available prior art, since the formation of a waveguide using lateral confinement resulting from index modification of a guiding layer and vertical confinement by layers bonded above and below the guiding layer by direct interfacial bonding is not suggested by the available prior art documents. The claims therefore meet the requirements of Article 33(2) and (3) PCT

Claims 2 to 10 and 12

These claims define specific embodiments of the inventive concept of claims 1 and 11, and hence also meet the requirements of Article 33(2) and (3) PCT.

Concerning Section VIII

1. From the discussion of the technical problem in the passage spanning pages 1 and 2 of the present application, it is clear that the technical problem addressed by the application, and its solution, relate to waveguides formed between two "superstructure" layers. Since the independent claims 1 and 11 do not define that the superstructure layers have a refractive index such as to provide vertical confinement, it is apparent that these claims lack a technical feature which is essential to the invention, so that they do not clearly define the invention. These claims therefore do not meet the requirements of Article 6 PCT.

2. The application contains on page 11 a list of documents entitled "Publication References". The remainder of the application however contains no reference to these documents, so that their significance is not apparent.

FABRICATION OF OPTICAL WAVEGUIDES

This invention relates to the fabrication of optical waveguides.

One known technique for fabricating optical waveguides is the so-called direct bonding (or direct interfacial bonding) technique.

Direct bonding (DB) is a fabrication technique that uses the Van der Waals forces present when two atomically flat bodies approach each other to create a bond between the bodies. If the bodies are laminas of optical material having appropriate refractive indices, the material laminas can be joined to form waveguiding boundaries.

In one established way to form such a bond the surfaces of two pieces of optical material are polished so as to be very flat (i.e. substantially flat at atomic dimensions). The crystalline structures of the two polished faces are preferably aligned with each other and the polished faces are pressed together. A heat treatment can be useful to encourage a pyroelectric effect and the exchange of electrons between the two surfaces. This gives rise to an electrostatic attraction between the two surfaces, which tends to expel any remaining air or liquid from between the two surfaces. A final annealing step can improve the bond strength further.

A DB bond can be formed irrespective of the lattice constants and orientation of the bodies involved and causes no degradation on the crystalline microstructure or either material. By contacting surfaces in such a non-destructive way, DB preserves the bulk characteristics of each bonded material whilst avoiding possible problems caused by lattice defects, such as increased propagation loss and optical damage.

This invention provides an optical waveguide comprising at least a guiding lamina of optical material bonded by direct interfacial bonding to a superstructure lamina of optical material, in which regions of the guiding lamina have modified optical properties so as to define a light guiding path along the guiding lamina.

The invention recognises and addresses the shortcomings of previous proposals for the use of DB structures in optical waveguides. In such previous proposals, a flat lamina of a material having a raised refractive index (forming a waveguide "core") is bonded between two laminas of material having a lower refractive index (forming a waveguide "superstructure"). While this provided a bulk guiding structure, the large

method which has already been demonstrated in the production of $LiNbO_3$ planar waveguides for electro-optic applications. One of the primary attractions offered by this technique is that the non-linearity and domain characteristics of the PPLN structure after bonding should remain unchanged from the bulk material - a combination that annealed proton exchange and Ti indiffusion methods are close to achieving, but not yet at their full theoretical efficiencies. A further advantage of the present method is the extra flexibility available when designing devices, as combinations of multiple laminas with different material properties are now possible.

Viewed from a second aspect this invention provides a method of fabricating an optical waveguide, the method comprising the steps of:

(a) bonding, by direct interfacial bonding, a guiding lamina of optical material to a superstructure lamina of optical material; and

(b) before, during or after step (a), modifying optical properties of regions of the guiding lamina so as to define a light guiding path along the guiding lamina.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of a waveguide formed using a lamina of PPLN bonded between two laminas of lithium tantalate;

Figure 2 schematically illustrates a second harmonic generator using the waveguide of Figure 1;

Figure 3 is a graph relating the square root of second harmonic power to launch power for the apparatus of Figure 2;

Figures 4 and 5 are schematic diagrams illustrating the fabrication of a waveguide according to an embodiment of the invention using an indiffusion technique; and

Figure 6 schematically illustrates a waveguide according to a further embodiment of the invention.

In the following description, preparation and use of an example waveguide as a second harmonic generator will first be described with reference to Figures 1 to 3. Then, other waveguides also forming embodiments of the invention will be described.

CLAIMS

1. An optical waveguide comprising at least a guiding lamina of optical material bonded by direct interfacial bonding to a superstructure lamina of optical material, in which regions of the guiding lamina have modified optical properties so as to define a light guiding path along the guiding lamina.

2. A waveguide according to claim 1, comprising a further superstructure lamina bonded by direct interfacial bonding to the guiding lamina.

3. A waveguide according to claim 1 or claim 2, in which the guiding lamina is formed of a ferroelectric material.

4. A waveguide according to claim 3, in which the guiding lamina is formed of lithium niobate.

5. A waveguide according to claim 3 or claim 4, in which the modified regions are electrically poled regions of the guiding lamina.

6. A waveguide according to claim 5, in which the modified regions are spatially periodical electrically poled regions of the guiding lamina.

7. A waveguide according to any one of claims 1 to 5, in which the modified regions are formed by indiffusion of one or more dopant materials into the guiding lamina.

8. A waveguide according to any one of claims 1 to 7, in which at least part of the modified regions form the light-guiding path.

9. A waveguide according to any one of claims 1 to 7, in which the light guiding path is formed of an unmodified region of the guiding lamina, the modified regions defining boundaries of the light guiding path.

10. An optical parametric device comprising:
a waveguide according to any one of the preceding claims; and
means for launching an input optical signal into the waveguide.

11. A device according to claim 10, comprising:
an output filter for filtering light emerging from the waveguide to reduce components at the wavelength of the input optical signal.

12. A method of fabricating an optical waveguide, the method comprising the steps of:

(a) bonding, by direct interfacial bonding, a guiding lamina of optical material to a superstructure lamina of optical material; and

(b) before, during or after step (a), modifying optical properties of regions of the guiding lamina so as to define a light guiding path along the guiding lamina.

13. A method according to claim 12, comprising the steps of:

(c) after steps (a) and (b), removing material from the guiding lamina to reduce the thickness of the guiding lamina; and

(d) after step (c), bonding, by direct interfacial bonding, a further superstructure lamina to the guiding lamina.

14. A method according to claim 13, comprising:

(e) before step (a), indiffusing and/or out-diffusing material to/from one face of the guiding lamina to modify regions of the guiding lamina, that face being bonded to the superstructure lamina in step (a); and

(f) before step (d), indiffusing and/or out-diffusing material to/from the exposed face of the guiding lamina to modify regions of the guiding lamina, that face being bonded to the further superstructure lamina in step (d).

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	**FOR FURTHER ACTION**	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
P/5372.WO		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/GB 99/ 03055	14/09/1999	14/09/1998
Applicant		
UNIVERSITY OF SOUTHAMPTON et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 4 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

[ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

[ ] contained in the international application in written form.
[ ] filed together with the international application in computer readable form.
[ ] furnished subsequently to this Authority in written form.
[ ] furnished subsequently to this Authority in computer readble form.
[ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
[ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title**,

[X] the text is approved as submitted by the applicant.
[ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

[ ] the text is approved as submitted by the applicant.
[X] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1

[X] as suggested by the applicant.
[ ] because the applicant failed to suggest a figure.
[ ] because this figure better characterizes the invention.
[ ] None of the figures.

Box III TEXT OF THE ABSTRACT (Continuation of item 5 f the first sheet)

Line 3 should read as follows "An optical waveguide comprising at least a guiding lamina (10) of optical material".

Line 4 should read as follows "bonded by direct interfacial bonding to a superstructure lamina (20) of optical material, in".

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 99/03055

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/12 G02F1/377

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 598 395 A (MATSUSHITA ELECTRIC INDUSTRIAL CO LTD) 25 May 1994 (1994-05-25) example 21	1,3,4, 7-9,12
X	PELISSIER S ET AL: "NEW TECHNIQUE TO PRODUCE BURIED CHANNEL WAVEGUIDES IN GLASS" OPTICAL ENGINEERING,US,SOC. OF PHOTO-OPTICAL INSTRUMENTATION ENGINEERS. BELLINGHAM, vol. 37, no. 4, page 1111-1114 XP000771670 ISSN: 0091-3286 figure 1	1,7,8,12

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 December 1999	16/12/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lord, R

1

[redacted]tional Application No
PCT/GB 99/03055

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	ROSS G W ET AL: "GENERATION OF HIGH-POWER BLUE LIGHT IN PERIODICALLY POLED LINBO3" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 23, no. 3, page 171-173 XP000741206 ISSN: 0146-9592 cited in the application the whole document ---	3-6,10, 11
A	US 5 122 852 A (CHANG WINSTON K ET AL) 16 June 1992 (1992-06-16) column 3, line 31 - line 36 ---	3,4
A	YOO S J B ET AL: "QUASI-PHASE-MATCHED SECOND-HARMONIC GENERATION IN ALGAAS WAVEGUIDESWITH PERIODIC DOMAIN INVERSION ARCHIEVED BY WAFER-BONDING" APPLIED PHYSICS LETTERS,US,AMERICAN INSTITUTE OF PHYSICS. NEW YORK, vol. 66, no. 25, page 3410-3412 XP000520298 ISSN: 0003-6951 the whole document -----	5,6,10, 11

1

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0598395 A	25-05-1994	DE 69323958 D	22-04-1999
		DE 69323958 T	16-09-1999
		JP 6222229 A	12-08-1994
		KR 137125 B	15-06-1998
		US 5485540 A	16-01-1996
		US 5785874 A	28-07-1998
US 5122852 A	16-06-1992	NONE	

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WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G02B 6/12, G02F 1/377	A1	(11) International Publication Number: WO 00/16140 (43) International Publication Date: 23 March 2000 (23.03.00)

(21) International Application Number: PCT/GB99/03055

(22) International Filing Date: 14 September 1999 (14.09.99)

(30) Priority Data:
9820024.9 14 September 1998 (14.09.98) GB

(71) Applicant (*for all designated States except US*): UNIVERSITY OF SOUTHAMPTON [GB/GB]; Highfield, Southampton, Hampshire SO19 1BJ (GB).

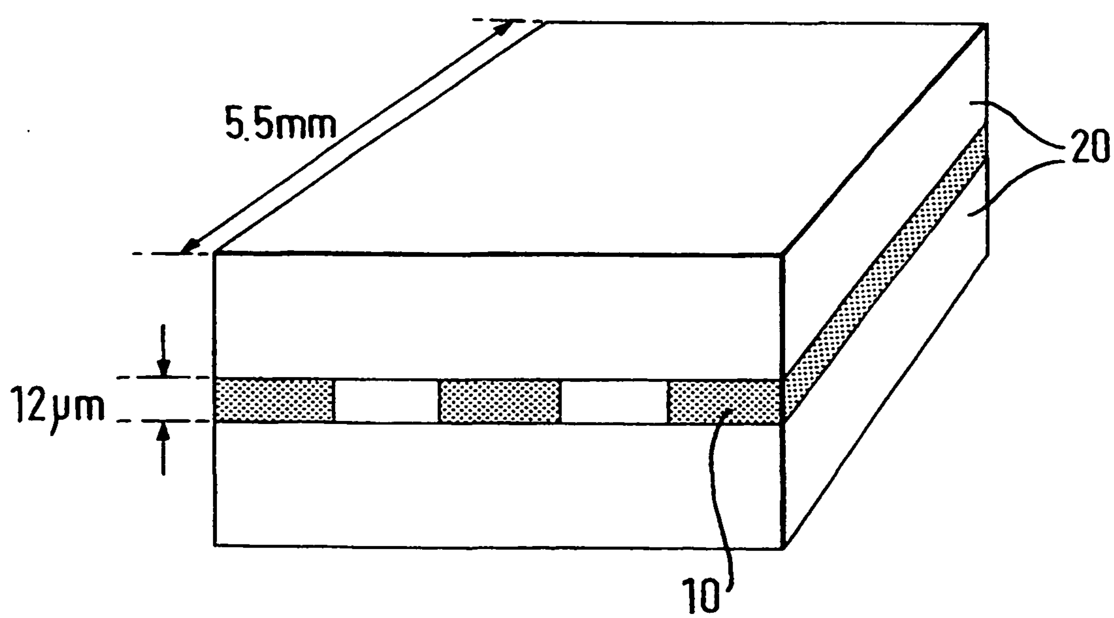
(72) Inventors; and
(75) Inventors/Applicants (*for US only*): SMITH, Peter, George, Robin [GB/GB]; 38 Eight Acres, Romsey, Hampshire S051 5BQ (GB). ROSS, Graeme, William [GB/GB]; 35 Gladstone Place, Queen's Cross, Aberdeen AB10 6UX (GB). HANNA, David, Colin [GB/GB]; 346 Hill Lane, Shirley, Southampton, Hampshire SO15 7PH (GB). SHEPHERD, David, P. [GB/GB]; Flat 2, 116 Highfield Lane, Highfield, Southampton, Hampshire SO17 1NP (GB). GAWITH, Colin, Barry, Edmund [GB/GB]; 24 Upland Court Road, Harold Wood, Romford, Essex RM3 0TT (GB).

(74) Agent: TURNER, James, Arthur; D Young & Co., 21 New Fetter Lane, London EC4A 1DA (GB).

(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: FABRICATION OF OPTICAL WAVEGUIDES



(57) Abstract

An optical waveguide comprising at least a guiding lamina (10) of optical material bonded by direct interfacial bonding to a superstructure lamina (20) of optical material, in which regions of the guiding lamina have modified optical properties so as to define a light guiding path along the guiding lamina. In a particular example, a periodically poled $LiNbO_3$ planar waveguide is buried in $LiTaO_3$ by direct interfacial bonding and precision polishing techniques and used in an optical frequency doubling system.

INTERNATIONAL SEARCH REPORT

In .tional Application No
PCT/GB 99/03055

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/12 G02F1/377

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 598 395 A (MATSUSHITA ELECTRIC INDUSTRIAL CO LTD) 25 May 1994 (1994-05-25) example 21 ---	1,3,4, 7-9,12
X	PELISSIER S ET AL: "NEW TECHNIQUE TO PRODUCE BURIED CHANNEL WAVEGUIDES IN GLASS" OPTICAL ENGINEERING,US,SOC. OF PHOTO-OPTICAL INSTRUMENTATION ENGINEERS. BELLINGHAM, vol. 37, no. 4, page 1111-1114 XP000771670 ISSN: 0091-3286 figure 1 ---	1,7,8,12

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 December 1999	16/12/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Lord, R

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Int ional Application No
PCT/GB 99/03055

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ROSS G W ET AL: "GENERATION OF HIGH-POWER BLUE LIGHT IN PERIODICALLY POLED LINBO3" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 23, no. 3, page 171-173 XP000741206 ISSN: 0146-9592 cited in the application the whole document ---	3-6,10, 11
A	US 5 122 852 A (CHANG WINSTON K ET AL) 16 June 1992 (1992-06-16) column 3, line 31 - line 36 ---	3,4
A	YOO S J B ET AL: "QUASI-PHASE-MATCHED SECOND-HARMONIC GENERATION IN ALGAAS WAVEGUIDESWITH PERIODIC DOMAIN INVERSION ARCHIEVED BY WAFER-BONDING" APPLIED PHYSICS LETTERS,US,AMERICAN INSTITUTE OF PHYSICS. NEW YORK, vol. 66, no. 25, page 3410-3412 XP000520298 ISSN: 0003-6951 the whole document -----	5,6,10, 11

1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 99/03055

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 5122852 A	16-06-1992	NONE	

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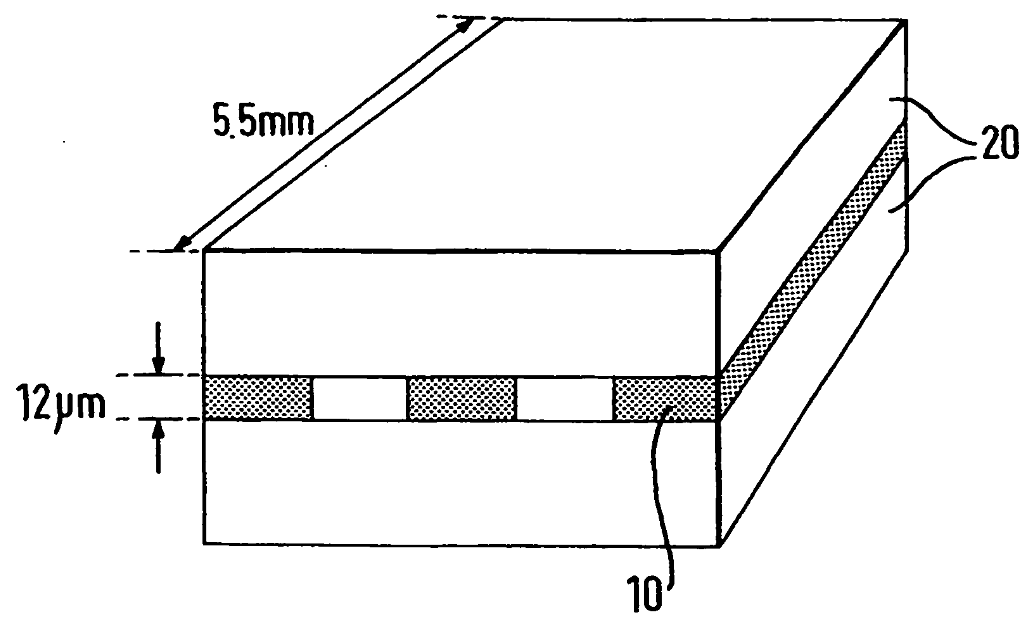
(54) Title: FABRICATION OF OPTICAL WAVEGUIDES



(57) Abstract

An optical waveguide comprising at least a guiding lamina (10) of optical material bonded by direct interfacial bonding to a superstructure lamina (20) of optical material, in which regions of the guiding lamina have modified optical properties so as to define a light guiding path along the guiding lamina. In a particular example, a periodically poled $LiNbO_3$ planar waveguide is buried in $LiTaO_3$ by direct interfacial bonding and precision polishing techniques and used in an optical frequency doubling system.

FABRICATION OF OPTICAL WAVEGUIDES

This invention relates to the fabrication of optical waveguides.

One known technique for fabricating optical waveguides is the so-called direct bonding (or direct interfacial bonding) technique.

Direct bonding (DB) is a fabrication technique that uses the Van der Waals forces present when two atomically flat bodies approach each other to create a bond between the bodies. If the bodies are laminas of optical material having appropriate refractive indices, the material laminas can be joined to form waveguiding boundaries.

In one established way to form such a bond the surfaces of two pieces of optical material are polished so as to be very flat (i.e. substantially flat at atomic dimensions). The crystalline structures of the two polished faces are preferably aligned with each other and the polished faces are pressed together. A heat treatment can be useful to encourage a pyroelectric effect and the exchange of electrons between the two surfaces. This gives rise to an electrostatic attraction between the two surfaces, which tends to expel any remaining air or liquid from between the two surfaces. A final annealing step can improve the bond strength further.

A DB bond can be formed irrespective of the lattice constants and orientation of the bodies involved and causes no degradation on the crystalline microstructure or either material. By contacting surfaces in such a non-destructive way, DB preserves the bulk characteristics of each bonded material whilst avoiding possible problems caused by lattice defects, such as increased propagation loss and optical damage.

This invention provides an optical waveguide comprising at least a guiding lamina of optical material bonded by direct interfacial bonding to a superstructure lamina of optical material, in which regions of the guiding lamina have modified optical properties so as to define a light guiding path along the guiding lamina.

The invention recognises and addresses the shortcomings of previous proposals for the use of DB structures in optical waveguides. In such previous proposals, a flat lamina of a material having a raised refractive index (forming a waveguide "core") is bonded between two laminas of material having a lower refractive index (forming a waveguide "superstructure"). While this provided a bulk guiding structure, the large

lateral dimension of the flat "core" lamina meant that the arrangement was not useful for many waveguiding applications or as a single-mode waveguide.

In contrast, in the invention, regions of the core lamina have modified optical properties so as to define a light guiding path along the core lamina. This can give a greatly increased flexibility of use and allow the guiding path to be much more tightly defined than in previous arrangements.

Although the method is suitable for use with many types of materials, such as glasses, it is preferred that the core lamina is a ferroelectric material, allowing the modified regions to be generated by electrical poling.

A particularly useful ferroelectric material having well-studied optical and electrical properties, is periodically poled lithium niobate (PPLN). PPLN combines a large non-linear coefficient, a widely-controllable phase-matching wavelength, and zero walk-off characteristics that make it an ideal material to achieve quasi-phase matching (QPM) for non-linear frequency conversion. With recent improvements in the efficiency of second-harmonic generation (SHG) within PPLN substrates, it is recognised in the present invention that the use of such a material in an appropriate waveguide geometry formed using the invention can provide a realisation of various compact non-linear devices based on harmonic or parametric generation.

The present method is particularly appropriate for use with PPLN, and has several advantages over other techniques for fabricating waveguides using PPLN such as the so-called "annealed proton exchange" technique and the "titanium indiffusion" technique, both of which act on a single PPLN crystal and modify the crystal near the surface in order to create regions of higher refractive index for optical confinement.

Previous experiments investigating the bonding characteristics of PPLN have been directed towards fabricating thick multi-laminated stacks of the material for a large physical aperture, and thus high power applications. In contrast, creating a sufficiently thin lamina of PPLN increases the average pump intensity applied to the domain-inverted structure via optical confinement, and thus allows efficient SHG even at low pump powers. Fabrication of such a device is obtainable by bonding PPLN onto a suitable substrate before precision polishing down to waveguide dimensions, a

method which has already been demonstrated in the production of $LiNbO_3$ planar waveguides for electro-optic applications. One of the primary attractions offered by this technique is that the non-linearity and domain characteristics of the PPLN structure after bonding should remain unchanged from the bulk material - a combination that annealed proton exchange and Ti indiffusion methods are close to achieving, but not yet at their full theoretical efficiencies. A further advantage of the present method is the extra flexibility available when designing devices, as combinations of multiple laminas with different material properties are now possible.

Viewed from a second aspect this invention provides a method of fabricating an optical waveguide, the method comprising the steps of:

(a) bonding, by direct interfacial bonding, a guiding lamina of optical material to a superstructure lamina of optical material; and

(b) before, during or after step (a), modifying optical properties of regions of the guiding lamina so as to define a light guiding path along the guiding lamina.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of a waveguide formed using a lamina of PPLN bonded between two laminas of lithium tantalate;

Figure 2 schematically illustrates a second harmonic generator using the waveguide of Figure 1;

Figure 3 is a graph relating the square root of second harmonic power to launch power for the apparatus of Figure 2;

Figures 4 and 5 are schematic diagrams illustrating the fabrication of a waveguide according to an embodiment of the invention using an indiffusion technique; and

Figure 6 schematically illustrates a waveguide according to a further embodiment of the invention.

In the following description, preparation and use of an example waveguide as a second harmonic generator will first be described with reference to Figures 1 to 3. Then, other waveguides also forming embodiments of the invention will be described.

Figure 1 schematically illustrates a waveguide formed as a directly bonded sandwich of a lamina 10 of PPLN between two laminas 20 of lithium tantalate ($LiTaO_3$).

The PPLN lamina 10 is in the form of a PPLN grating, in that the lithium niobate ($LiNbO_3$) material is poled in a periodic, "striped" arrangement. These "stripes" of alternately poled regions in the lithium niobate material are shown schematically in Figure 1 as alternate black and white stripes, although it will be appreciated that in reality the periodic poling structure would almost certainly not be detectable by the human eye.

Production of the PPLN grating began with a 0.5-mm-thick single domain z-cut $LiNbO_3$ sample of about 15 mm x 15 mm surface area. A photoresist pattern was created on the z-face of the crystal by photolithography. This formed regions on the crystal surface which are covered by an electrical insulator, and regions which are not so covered. A liquid electrode was then applied to the partially insulated surface, and domain inversion in the z-axis was performed at room temperature by the application of a single high voltage pulse of ~ 11 kV through the liquid electrode. This resulted in three 5.5-mm-long PPLN gratings, positioned in the centre of the $LiNbO_3$ sample at 1 mm intervals. Grating periods of 6.58, 6.50, and 6.38 μm were created, the first two of which are suitable for frequency doubling of a Nd:YAG laser operating at 1064 nm.

$LiTaO_3$ was chosen as a suitable material for both the substrate and superstructure laminas as it combines thermal characteristics that are a good match for $LiNbO_3$, an important pre-requisite when annealing bonds at high temperatures, together with a refractive index lower than that of $LiNbO_3$.

Each $LiTaO_3$ substrate was 0.5-mm-thick and shaped relative to the PPLN sample to provide a bonding area of about 12mm x 10 mm between the two optically flat surfaces. To form a bond between an $LiTaO_3$ substrate and the PPLN grating, the two materials were first cleaned, then a mixture of H_2O_2-NH_4OH-H_2O (1:1:6) was applied to both materials, followed by several minutes of rinsing in de-ionised water, in order to render their surfaces hydrophilic.

Contacting of the PPLN and $LiTaO_3$ laminas was performed at room temperature with both samples aligned along the same crystalline orientation. A heat treatment of 120°C immediately followed crystal contact to induce the pyroelectric effect at the DB interface. The resultant electrostatic attraction forced any excess air or liquid from between the two surfaces, whilst bringing them close enough to encourage the formation of hydrogen bonds. This effect was evident by the elimination of most contact fringes at the crystal interface. Annealing of the bonded sample at 320°C for 6 hours provided a bond strength sufficient for further machining, and the PPLN region was lapped down to obtain a waveguiding lamina of 12-μm-thickness.

The second superstructure lamina of $LiTaO_3$ was then added as above. The final DB structure included bonded interfaces of about 12mm x 10 mm above and below the PPLN core, although evidence of small unbonded regions at the edges of the sample were detected by the presence of optical fringes. The unnecessary material surrounding the gratings was later removed using dicing equipment and the waveguide end-faces were then polished to a parallel optical finish. Dimensions of the resulting buried PPLN planar structure are given schematically in Figure 1.

An upper limit for the value of the propagation loss of the waveguide structure was found by measuring the transmission of a 1064 nm laser beam when end-launched into the waveguide. It was noted that the transmission changed between the PPLN and unpoled $LiNbO_3$ sections, although this was not due to SHG. The launch from a microscope objective was empirically optimised for each region and maximum transmissions of 81% were found at the edges of the poled regions (where the best SHG occurred) and throughout the unpoled $LiNbO_3$ sections, whilst 65% transmission was obtained at the centre of the PPLN region. Thus, taking into account the 5.5-mm-length of the grating, an upper-limit to the propagation loss in each section can be placed as 1.7 dB cm^{-1} for the PPLN edges and unpoled $LiNbO_3$ regions, and 3.4 dB cm^{-1} for the central PPLN region. In reality, these transmission figures also include a certain loss due to non-perfect launching and so the propagation losses are likely to be much lower. Indeed, DB waveguides in garnets and glasses for laser applications have shown losses of ~0.5 dB cm^{-1} and less.

To test the non-linear properties of the buried PPLN structure. the SHG characteristics of the 6.50 μm grating were investigated. This grating, which occupied the middle section of the PPLN waveguide, successfully suppressed the photorefractive effect at its phase-matching temperature of 174.1°C and so was chosen for further analysis. The 1064 nm pump source was a cw diode-pumped Nd:YAG laser 30 operating with multi-axial modes. The linear polarisation state was rotated with a half-wave plate (not illustrated) to be parallel with the z-axis of the PPLN in order to access the material's largest non-linear coefficient (d_{33}). Focusing of the pump radiation for launching into the waveguide was performed using a combination of microscope objectives and cylindrical lenses, as shown in Figure 2. In particular, the initially circular pump beam was passed through a spherical collimating lens 40 and into a x2.4 cylindrical-lens telescope 50 to produce widening in the non-guided direction before being focused onto a poled region of the PPLN waveguide device 70 of Figure 1 by a x10 microscope objective 60. Such a combination of optics was chosen to provide good launch efficiency whilst helping to reduce divergence in the horizontal unguided plane. This resulted in a pump source with a line focus and measured spot sizes of 4±1 μm in the guided direction and 11±1 μm in the non-guided direction.

It should be noted that focusing to a waist in the non-guided plane at the input face is not necessarily the optimum condition for maximum SHG efficiency. However, it was used in this demonstration due to the simplicity of having one x10 objective as the focusing element instead of a more complicated cylindrical-lens launching arrangement. Also, for this initial demonstration, both the input and output end-faces of the waveguide were polished but left uncoated, leading to 14% reflection losses at each face.

The waveguide device 70 was placed in an oven 80 to maintain the waveguide's temperature at the phase-matching temperature of 174.1°C.

A second x10 microscope objective 90 was used to collect the transmitted light from the waveguide. This was followed by an infra-red filter 100 to block any throughput from the pump beams, allowing the generated green output of the PPLN to

be measured by an optical power meter. For 204 mW of launched pump power (λ = 1064 nm), a second-harmonic (SH) power of 1.8 mW (λ = 532 nm) was generated internal to the crystal. Figure 3 shows a plot of the square root of the SH power versus launched pump power, revealing a quadratic dependence between the measured values.

It should of course be noted that the system of Figure 2 is a specific example of an optical parametric device. The waveguide would be suitable for use in many other such devices.

Due to the unusual pumping geometry used while testing the PPLN waveguide, any calculation of the SHG efficiency from the device would be complicated. Instead, the most interesting comparison to make is with a calculation of the SH power expected from a similar length of bulk PPLN with optimised focusing in the centre of the grating. Assuming a non-linear coefficient of 16 pm V^{-1} (a value consistent with results in bulk experiments using similarly produced PPLN gratings), it is possible to produce a SH output power of 1.3 mW in the bulk material - a lower result than the 1.8 mW obtained from the direct-bonded waveguide. Therefore, it would appear that even with non-optimum focusing and only one guided dimension, the buried PPLN device shows an improved SHG efficiency over the bulk material.

Characterisation of the output modes of the PPLN waveguide was performed by the use of a video camera and PC-based evaluation software. Surprisingly, it was observed that both the 1064 nm throughput and the SH generated 532 nm radiation from the PPLN waveguide were in the fundamental spatial mode, an unexpected result for a 12-μm-thick guide with such a large index difference ($\Delta n_e \approx 1\%$). Indeed, only by using a deliberately poor launch was it possible to excite anything other than the fundamental mode at 1064 nm. Even more unusual was the result that the 1064 nm throughput from the unpoled $LiNbO_3$ region within the same buried structure was multi-spatial-mode in nature. This clear difference in the mode properties, combined with the apparently different transmissions described earlier, suggests that the index profile of the PPLN section is different to that of the unpoled $LiNbO_3$ section.

In summary, for the first embodiment of the invention these experiments demonstrate the successful prototype fabrication of a 12-μm-thick, 5.5-mm-long,

symmetrical PPLN waveguide buried in $LiNbO_3$ by DB. Using the 6.50-μm-period PPLN grating at an elevated temperature of 174°C, an efficient quasi-phase-matched frequency doubling of the 1064 nm line of a cw diode-pumped Nd:YAG laser has been demonstrated. For 204 mW of fundamental pump power, nearly 2 mW of green power was generated at an output wavelength of 532 nm. This result was obtained with non-optimum focusing conditions but remains higher than the theoretical expectation for a similar length of bulk material. The waveguiding properties were shown to be different in the PPLN and unpoled $LiNbO_3$ regions of the sample, with the PPLN section showing a surprising single-spatial-mode behaviour. These results suggest that the production of longer buried waveguides, potentially incorporating channel structures, should lead to highly-efficient non-linear devices. With a full characterisation of propagation losses and effects of strain upon the index profile, the DB technique should allow extra freedom, and hence new device possibilities, in the choice of non-linear waveguiding structures.

The techniques described above are not limited to PPLN, but can be applied to any optically useful poled ferroelectric material such as $LiTaO_3$, doped $LiNbO_3$ (e.g. Mg-, Ti- or rare earth doped), strontium barium niobate, barium titanate, potassium titanyl phosphate and its isomorphs, polar semiconductors such as gallium arsenide and so on.

The poling of the PPLN can be carried out before, during, between and/or after the bonding stages. If the poling is carried out other than before the bonding stages and a ferroelectric material is used for the other laminas, then those other laminas can also end up being poled. This may change the guiding properties of the waveguide but does not prevent operation as a waveguide. Indeed, the bonding properties may even be improved by this measure (or by poling the other laminas separately).

In the example above, a poled area is used to define a waveguiding path along the lamina 10, but with other substrates it may be found that an unpoled lamina offers a more appropriate path.

It is not necessary to surround the lamina 10 by two other laminas 20. Instead, one lamina 20 could be used, to form an "open sandwich" structure of just two

laminas. In this case the symmetry of the structure would be altered and the guided mode(s) would probably be different, but operation as a waveguide would still be possible.

The thickness of the lamina 10 can be altered, again altering the nature of the guided mode(s) in the waveguide. In this way, a single mode structure can be fabricated.

Referring now to Figures 4 and 5, a second embodiment using an indiffusion technique to define a waveguide path will be described.

In this second embodiment, a piece of PPLN 100 is made by the conventional electrical poling method. The piece 100 might be, for example, 500μm thick and several mm in the other two dimensions. One face 110 of the piece 100 is patterned with magnesium oxide (using a process of photolithography and vacuum evaporation or sputtering). The magnesium oxide lamina is less than about 400nm thick, and defines (by the parts not covered by the lamina) a waveguide path along the piece 100. The piece 100 is then heated to a temperature of between about 600°C and about 1200°C. This causes the magnesium oxide material to diffuse in and, in the indiffused regions 130, locally lower the refractive index.

The piece 100 is then bonded, by a direct bonding process applied to the face 110, to a $LiTaO_3$ substrate (140, Figure 5), before being polished down to a substantially uniform thickness of between, say, about 4μm and about 40μm.

A further magnesium oxide pattern is then deposited on the exposed (newly polished) face of the piece 100, and the heat treatment repeated. This causes the magnesium oxide to indiffuse from the other side, to match the indiffusion from the face 110. Regions 150 of reduced refractive index are thus formed, defining a waveguiding core 160.

This technique, or a complementary out-diffusion technique, is applicable not only to other ferroelectric materials (for examples, see above), but also to any substrates whose refractive index can be altered by an indiffusion technique, such as various glasses, polymers and other crystals. The common advantage shared between

all applications of this technique is that the guiding region 160 can be formed of unadulterated material.

Similarly, in all of the embodiments, the "superstructure" laminas can be of various materials such as unpoled $LiNbO_3$ or other suitable materials from the lists above.

It is possible to fabricate curved waveguide paths using the above techniques. In the case of the first embodiment, a poling pattern similar to that shown schematically in Figure 6 can be used, where a series of poled regions form a track 170 which bifurcates as a signal splitter. In the case of $LiNbO_3$ there is a preferred poling direction resulting form the crystal structure, but the arrangement of Figure 6 gets around this restriction to form curved or varying-direction paths using multiple displaced poled stripes.

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CLAIMS

1. An optical waveguide comprising at least a guiding lamina of optical material bonded by direct interfacial bonding to a superstructure lamina of optical material, in which regions of the guiding lamina have modified optical properties so as to define a light guiding path along the guiding lamina.

2. A waveguide according to claim 1, comprising a further superstructure lamina bonded by direct interfacial bonding to the guiding lamina.

3. A waveguide according to claim 1 or claim 2, in which the guiding lamina is formed of a ferroelectric material.

4. A waveguide according to claim 3, in which the guiding lamina is formed of lithium niobate.

5. A waveguide according to claim 3 or claim 4, in which the modified regions are electrically poled regions of the guiding lamina.

6. A waveguide according to claim 5, in which the modified regions are spatially periodical electrically poled regions of the guiding lamina.

7. A waveguide according to any one of claims 1 to 5, in which the modified regions are formed by indiffusion of one or more dopant materials into the guiding lamina.

8. A waveguide according to any one of claims 1 to 7, in which at least part of the modified regions form the light-guiding path.

9. A waveguide according to any one of claims 1 to 7, in which the light guiding path is formed of an unmodified region of the guiding lamina, the modified regions defining boundaries of the light guiding path.

10. An optical parametric device comprising:
a waveguide according to any one of the preceding claims; and
means for launching an input optical signal into the waveguide.

11. A device according to claim 10, comprising:
an output filter for filtering light emerging from the waveguide to reduce components at the wavelength of the input optical signal.

12. A method of fabricating an optical waveguide, the method comprising the steps of:

(a) bonding, by direct interfacial bonding, a guiding lamina of optical material to a superstructure lamina of optical material; and

(b) before, during or after step (a), modifying optical properties of regions of the guiding lamina so as to define a light guiding path along the guiding lamina.

13. A method according to claim 12, comprising the steps of:

(c) after steps (a) and (b), removing material from the guiding lamina to reduce the thickness of the guiding lamina; and

(d) after step (c), bonding, by direct interfacial bonding, a further superstructure lamina to the guiding lamina.

14. A method according to claim 13, comprising:

(e) before step (a), indiffusing and/or out-diffusing material to/from one face of the guiding lamina to modify regions of the guiding lamina, that face being bonded to the superstructure lamina in step (a); and

(f) before step (d), indiffusing and/or out-diffusing material to/from the exposed face of the guiding lamina to modify regions of the guiding lamina, that face being bonded to the further superstructure lamina in step (d).

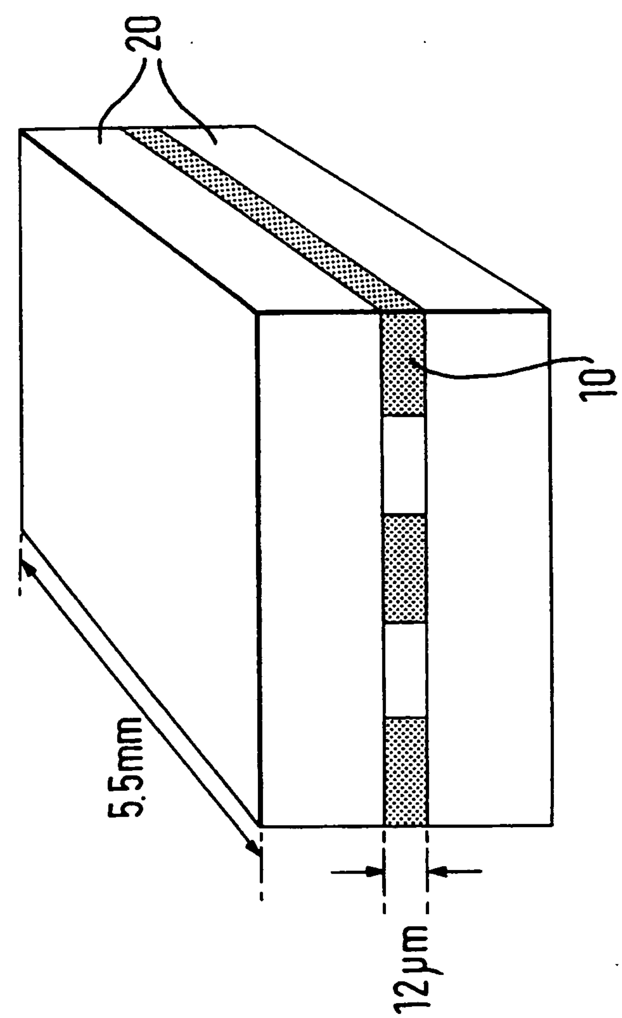
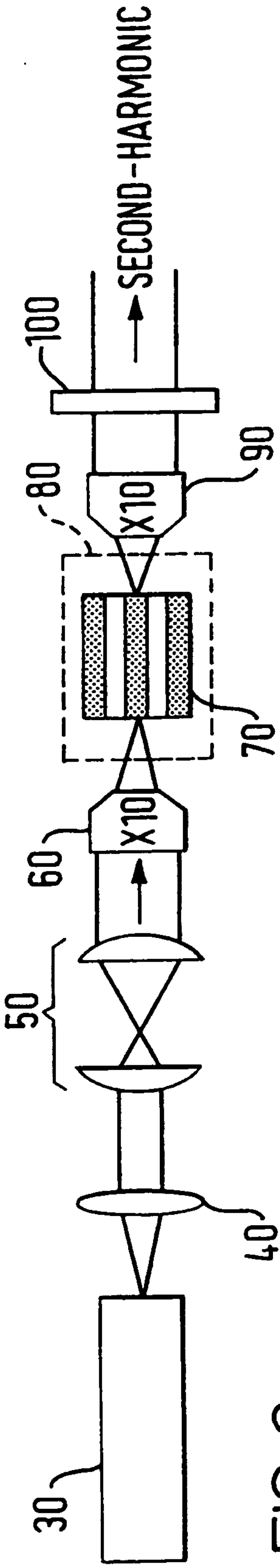
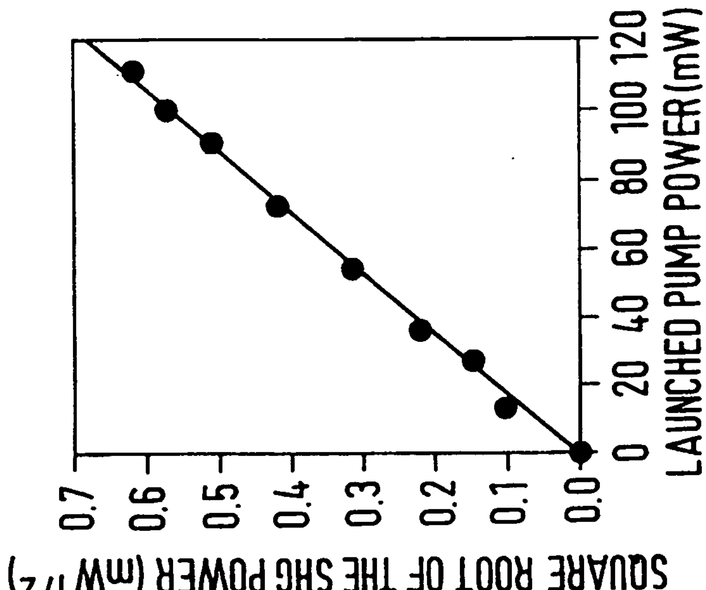


FIG. 1



SECOND-HARMONIC
100
90
80
X10
70
60
X10
50
40
30

FIG. 2



SQUARE ROOT OF THE SHG POWER (mW1/2)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 20 40 60 80 100 120
LAUNCHED PUMP POWER (mW)

FIG. 3

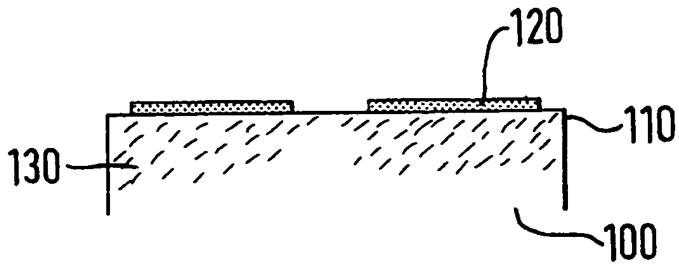


FIG. 4

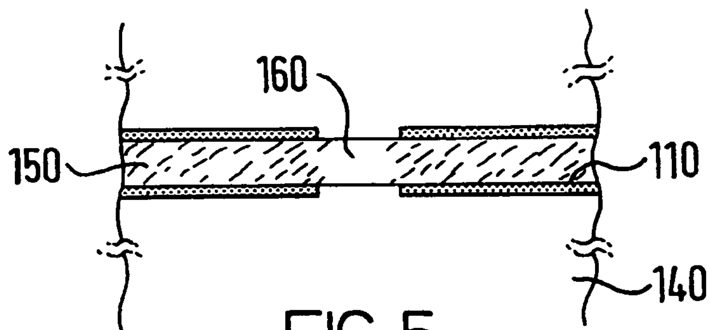


FIG. 5

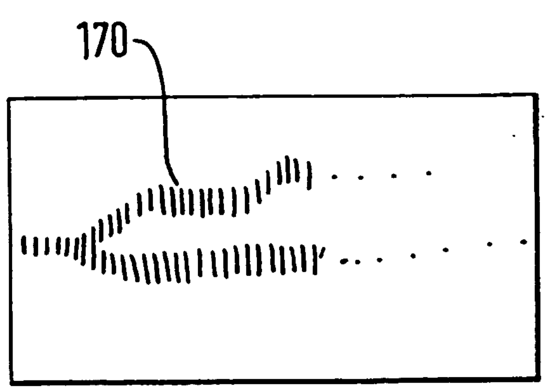


FIG. 6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 99/03055

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/12 G02F1/377

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 598 395 A (MATSUSHITA ELECTRIC INDUSTRIAL CO LTD) 25 May 1994 (1994-05-25) example 21	1,3,4, 7-9,12
X	PELISSIER S ET AL: "NEW TECHNIQUE TO PRODUCE BURIED CHANNEL WAVEGUIDES IN GLASS" OPTICAL ENGINEERING,US,SOC. OF PHOTO-OPTICAL INSTRUMENTATION ENGINEERS. BELLINGHAM, vol. 37, no. 4, page 1111-1114 XP000771670 ISSN: 0091-3286 figure 1	1,7,8,12

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 December 1999	16/12/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lord, R

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Form PCT/ISA/210 (second sheet) (July 1992)

International Application No
PCT/GB 99/03055

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	ROSS G W ET AL: "GENERATION OF HIGH-POWER BLUE LIGHT IN PERIODICALLY POLED LINBO3" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 23, no. 3, page 171-173 XP000741206 ISSN: 0146-9592 cited in the application the whole document	3-6,10, 11
A	US 5 122 852 A (CHANG WINSTON K ET AL) 16 June 1992 (1992-06-16) column 3, line 31 - line 36	3,4
A	YOO S J B ET AL: "QUASI-PHASE-MATCHED SECOND-HARMONIC GENERATION IN ALGAAS WAVEGUIDESWITH PERIODIC DOMAIN INVERSION ARCHIEVED BY WAFER-BONDING" APPLIED PHYSICS LETTERS,US,AMERICAN INSTITUTE OF PHYSICS. NEW YORK, vol. 66, no. 25, page 3410-3412 XP000520298 ISSN: 0003-6951 the whole document	5,6,10, 11

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 99/03055

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0598395 A	25-05-1994	DE 69323958 D	22-04-1999
		DE 69323958 T	16-09-1999
		JP 6222229 A	12-08-1994
		KR 137125 B	15-06-1998
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